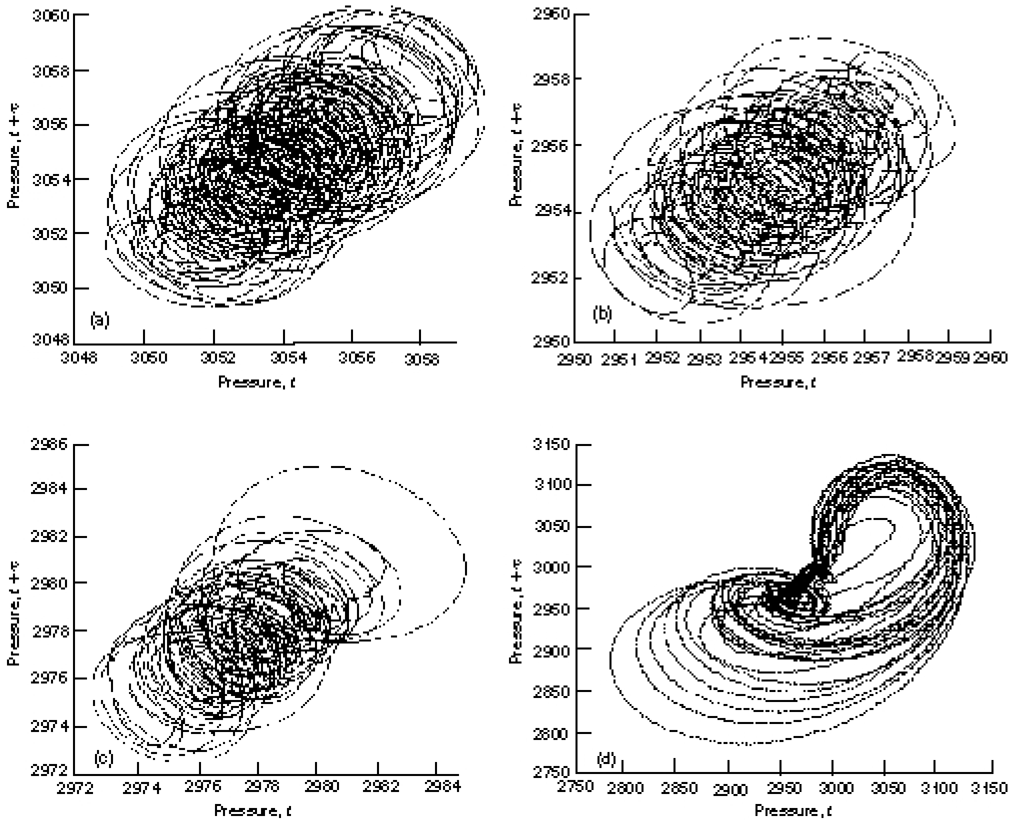
Chaotic Time Series Analysis Method Developed for Stall Precursor Identification in High-Speed Compressors

A new technique for rotating stall precursor identification in high-speed compressors has been developed at the NASA Lewis Research Center. This pseudo correlation integral method uses a mathematical algorithm based on chaos theory to identify nonlinear dynamic changes in the compressor. Through a study of four various configurations of a high-speed compressor stage, a multistage compressor rig, and an axi-centrifugal engine test, this algorithm, using only a single pressure sensor, has consistently predicted the onset of rotating stall.

Data for this algorithm have been collected from a single high-frequency-response pressure transducer located one chord length upstream of the rotor and flush mounted in the casing. The pressure signal data are input to the correlation integral algorithm. The algorithm calculates a phase plane portrait of the pressure data for one window in time. As pressure conditions change in the compressor, specifically through throttle area closing, the algorithm monitors dynamic changes in the phase plane portrait. As the phase portrait shrinks or enlarges, stretches or twists, the correlation integral calculation monitors these changes. From calculations performed on four various configurations of a high-speed compressor stage, the data confirm a sharp decrease in the correlation integral prior to the onset of rotating stall.

As an example, the phase plane portraits for a high-speed compressor stage are presented at four operational conditions in the figure. A phase plane portrait displays the pressure data on the *x*-axis and a time-delayed version on the *y*-axis. Part (a) shows the pressure signal for steady operation of the compressor stage with the throttle fully open. Part (b) shows the phase plane portrait of the compressor with the throttle partially closed, but still far from the stall condition. Part (c) shows the pressure signal very near the stall condition, and part (d) shows the compressor in full rotating stall. The phase plane portraits in parts (a) and (b) are very similar in physical nature, and their correlation integrals are identical. In part (c), the physical nature of the portrait has changed slightly and the correlation integral calculation has decreased. In the rotating stall condition of part (d), the portrait has changed significantly from the previous portraits and the correlation integral has dropped significantly. This decrease in correlation integral prior to rotating stall, which is a precursive signal that rotating stall will occur, is present in all test cases.



Phase plane portraits of pressure data from a high-speed compressor. (a) Steady phase plane portrait. (b) Phase plane portrait far from stall. (c) Phase plane portrait close to stall. (d) Phase plane portrait in rotating stall.

To provide a basis for comparison, we applied the traveling wave energy technique (ref. 1), which has been used extensively to study prestall data, to identical data sets (ref. 2). The correlation method was shown to have a potential advantage over the traveling wave energy method because it uses a single sensor for detection and does not require the data to detect changes in the behavior of the compressor. Both methods were used in this study to identify stall precursive events in the pressure fluctuations measured from circumferential pressure transducers located at the front face of the compressor rig. The correlation method successfully identified stall formation or changes in the compressor dynamics from data captured from four different configurations of a NASA Lewis single-stage high-speed compressor while it transitioned from stable operation to stall. The traveling-wave energy technique, which requires eight circumferentially located transducers, was not able to predict the onset of rotating stall for one of the test cases. The experimental results indicate that the correlation method provides warning of the onset of rotating stall at high speed. This method is being expanded into an online diagnostic and prediction tool as part of an integrated active stall control system.

References

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